

Renewable Energy in the Kingdom of Tonga; National Plan & PV Generation Systems

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Abstract—The Kingdom of Tonga is presently implementing its objective set out in the Tonga Energy Road Map (TERM) to “reduce Tonga’s vulnerability to oil price shocks and to achieve an increase in quality access to modern energy services in an environmentally sustainable manner”. TERM sets out to produce 50% of the country’s electricity through renewable resources. This paper investigates the TERM goals, timeline and progress to date. Two Photovoltaic generation projects that were commissioned in 2012 are presented as case studies and discussed.

Index Terms—Pacific Islands, Renewable Energy, Tonga Energy Road Map, Photovoltaic.

I. INTRODUCTION

The Kingdom of Tonga (Tonga), located in the South Pacific Ocean, is made up of 176 islands with a total land area of 748 km². The four main groups of islands of Tongatapu, Vava’u, Ha’apai and Niua’s comprise 36 inhabited islands with a total population of 103,036. Tongatapu has close to 73 % of the total Tongan population and is the only island group with an increasing population rate [1]. The Tongan population has grown at a rate of 1.0 % per annum between 2000-01 and 2010-11 and had a GDP of TOP \$7,553 (US \$4,384) per capita in 2010-11 [2].

Determined to reduce Tonga’s reliance on diesel fueled electricity and vulnerability to oil price shocks, the Tongan Government, in 2009, approved a policy to supply 50 % of Tonga’s energy through renewable resources. The policy aimed to improve energy security of Tonga while contributing to the reduction of global green-house gas (GHG) emissions. A number of studies and implementation of solar energy technologies have been carried out in Tonga since 1987. During 2009 and 2010, a number of studies focusing on Tonga’s renewable energy options, energy demand, energy conservation options and donor and institutional requirements were produced forming the basis of the “Tonga Energy Road Map 2010 - 2020” (TERM). The TERM sets out a ten year road map to reduce Tonga’s vulnerability to oil price shocks and achieve an increase in quality access to modern energy services in an environmentally sustainable manner. In 2011, the Government of Tonga (GoT) established a TERM Implementation Unit (TERM-IU) to coordinate the day to day activities towards achieving TERM objectives [3].

The approach by Tonga has set an example for neighboring countries in the Pacific Islands, like Vanuatu, to establish

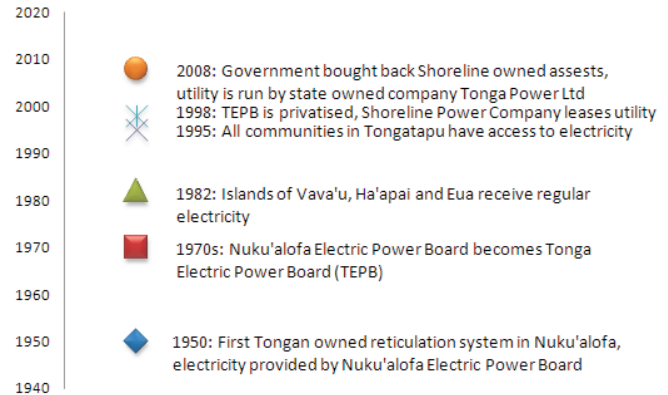


Fig. 1. Tonga Electricity History

energy road maps [4]. This paper presents TERM progress to date since publication in 2010 and presents and discusses two renewable energy projects that were implemented in Tonga in 2012.

II. TONGA ENERGY BACKGROUND

A. Tonga Power System Overview

Tonga’s power generation and network is owned by a state owned enterprise, Tonga Power Ltd (TPL). TPL generate, distribute and retail electricity on each of the four main islands. TPL’s largest power system is located in the main island of Tongatapu and makes up approximately 85 % of Tongan electric grid capacity. Fig 1 presents a brief history of Tonga’s electricity sector and TPL’s power system details are presented in Table I.

B. Tonga Energy Road Map Document

The TERM presents a summary of Tonga’s petroleum supply process, electricity demand, load forecast, electrical grid and off-grid status, institutional arrangements, and policy and legal frameworks. The TERM’s objective is to, “reduce Tonga’s vulnerability to oil price shocks and to achieve an increase in quality access to modern energy services in an environmentally sustainable manner” [5]. The TERM is a document designed to guide government action and donor partner support. Originally, it aimed to implement the government’s policy to supply 50 % of electricity through renewable energy

TABLE II
RECENT TONGA ENERGY PROJECTS

| Project Name | Est Start / Completion | Capacity (kW) | Project Cost | Source of Funds | Status |
|---|------------------------|---------------|--------------|---|-------------------|
| Micro Grid Development | Sep 13/ Sep 14 | 1000 | tbc | JICA | Feasibility Study |
| Tonga Village Network Upgrade | Jun 11 / Jun 13 | | NZ\$5.4m | NZAID | Ongoing |
| Vavau Solar Park | Jan 13 / Oct 13 | 500 | | UAE | Ongoing |
| Promoting Energy Efficiency in the Pacific: Phase 2 (PEEP2) | Nov 11 / Mar 15 | | | | Underway |
| Popua Solar (Maama mai) FArm | Nov 11 / Aug 12 | 1300 | NZ\$7.9m | NZAID | Complete |
| Power Sector Tariff Review | Sep 12 / Nov 12 | | USD\$0.14m | AusAID | Complete |
| Pacific Appliance Labelling and Standards (PALS) Programme | Jan 12 / tbc | | | Aust. Department of Climate Change and EE | Ongoing |

TABLE I
TONGA POWER LTD. POWER SYSTEM OVERVIEW

| Quantity | Tongatapu | Vava'u | Ha'apai | 'Eua |
|-----------------------------------|-----------|--------|---------|------|
| Total Diesel (kW) | 11,280 | 1,272 | 372 | 372 |
| Total Solar (kW) | 1,300 | | | |
| Transmission (kV) | 11 | 6.6 | 6.6 | 6.6 |
| Distribution (V) | 415 | 415 | 415 | 415 |
| Domestic Customers | 12,524 | 2,422 | 645 | 985 |
| Commercial Customers | 2,794 | 779 | 342 | 48 |
| Historic Peak Load (kW) | 8,400 | 1,010 | 355 | 310 |
| year occurred | 2008 | 2008 | 2007 | 2007 |
| Long term average Load Factor (%) | 63 | 57.5 | 57 | 47.5 |
| Load Growth (pre 08) (%) | 5.5 | 4.0 | 10.3 | 6.1 |

resources by 2012. The ten year road map aims to meet its objective in three strategic phases. Phase 0, 1 and 2 - institutional reformation of the energy sector, grant funded implementation of pilot projects and sustainable investment in energy sector, respectively. Originally, Phases 0 and 1 were thought to run in parallel and be completed within 18 months. Phase 2 was recommended to commence following a minimum of 12 months of operational data and experience from proof-of-concept projects.

C. Projects and Progress to Date

Table II presents recent TERM projects. In 2013, approximately 93.6 % of Tonga's electricity generation capacity is reliant on fossil fuel and the desired institutional reformation is yet to be completed.

Tonga energy stakeholders including the director of TERM-IU and the CEO of Tongan state owned electricity utility TPL were interviewed in 2012 to understand reasons behind delays associated with the implementation of TERM.

Reasons include the following concerns;

- 1) *Political* The energy sector was under the dispersed responsibility of seven separate ministries. The institutional reform was dependent on the political will and leadership of the Prime Minister and the heads of seven Ministries [6]. Following July 2012 government structural reform, five ministries including Prime Minister's office were responsible for the Tongan energy sector.
- 2) *Lack of operational plan and skill set* TERM-IU had conceived a draft Operational Business Plan but it was

never finalized or implemented. TERM itself does not provide operational guidelines, milestones and performance benchmarks. TERM-IU does not have the technical capacity or the skill set to disseminate energy related policies [7].

- 3) *Exclusion of in country technical experts* Processes and methods associated with TERM's energy sector reforms and decisions made by TERM-IU has excluded in-country technical experts from being able to provide input [8]. TPL have excellent knowledge of Tonga's power generation systems, power network and future needs from an operational point of view. Similarly, Energy Planning Unit (EPU) have worked in the off grid sector for more than two decades and can provide valuable insights [9]. The near complete exclusion has limited the amount of technical input and support that can be provided to TERM-IU, impeding on the delivery of TERM objective and milestones.

D. Discussion

The TERM progress is over 18 months behind the initial plan. Issues related to the delay can loosely be categorized into challenges associated with politics, in-country stakeholder engagement and a lack of an implementation plan with key milestones and key performance indicators. Despite these challenges, Tonga has successfully commissioned the 1.3 MW peak solar farm with the help of New Zealand Government and state owned enterprise Meridian Energy and continues to work on projects that align with TERM objective.

Much of the focus with the implementation of TERM to date has been on institutional reform and review of the existing energy sector. Thus, excluded input from TPL and EPU in planning. It is essential to engage all Tongan energy stakeholders, including TPL and EPU to fully understand and mitigate technical, economic and political risks during the implementation and operational phases of the TERM.

Stakeholder interviews and literature show that Tongan energy stakeholders, including TERM IU are in favor of creating one regulating body, a "Ministry of Energy" concept to regulate and enable utilities to operate independently. A successful completion of TERM's phase 0 and 1 is likely to see TERM IU disestablish by initiating a Ministry of Energy.

TABLE III
MAAMA MAI SITE INSTALLATION INFORMATION [11]

| Project | Field A | Field B | Total |
|--|---------|---------|--------|
| Total Site Area (m ²) | | | 25,370 |
| Total String Length | 5,215 | 9,470 | 14,686 |
| Total DC Cable Lengths (m) | 383 | 923 | 1,306 |
| No. of Modules | 2304 | 3,456 | 5,760 |
| No. of Array Guard Units | 6 | 9 | 15 |
| No. of Pods | 96 | 144 | 240 |
| Road Lengths at 4 m Wide (m) | 806 | 1,208 | 2,013 |
| Solar Array Footprint Area | 3,222 | 4,831 | 8,054 |
| Solar Panel Area Flat (m ²) | 3,863 | 5,795 | 9,658 |
| Solar Panel Area Pitched (m ²) | 3,732 | 5,598 | 9329 |

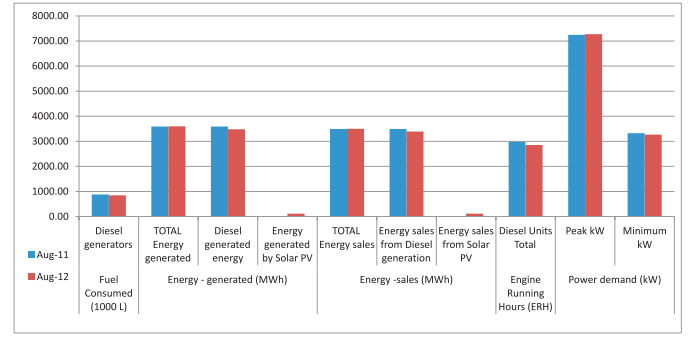


Fig. 3. Energy Comparison for August 2011 and 2012

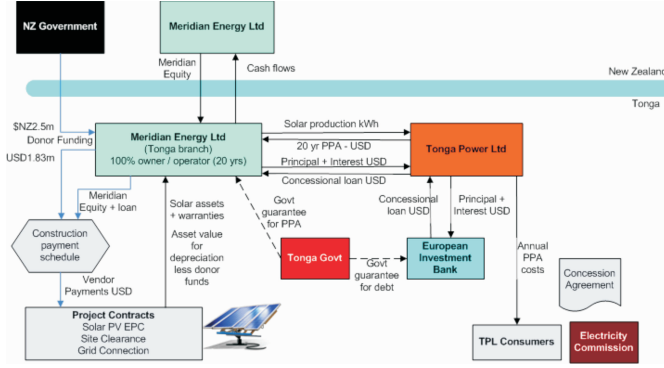


Fig. 2. Original Meridian Solar Joint Venture Relationship [12]

III. CASE STUDY 1; 1.3 MW MAAMA MAI SOLAR FARM

A. Project Background

Meridian Energy Ltd. is New Zealand's largest electricity generation company with hydro, wind and solar generation in New Zealand, Australia, Antarctica, the USA and now in Tonga. In 2009, Meridian Energy presented a Pacific Island solar strategy proposal to the New Zealand Aid Programme. The strategy identified Tonga as one of the three countries suited for the integration of 1 MW scale solar photovoltaic generation. The proposal was presented to respective state owned electricity company TPL and it was timely with the Government's development of the TERM at the time [10].

Maama Mai Solar Farm is Tonga's first solar power farm. It is located next Tongatapu's Popua Power Station, located south east of capital Nuku'alofa. Preliminary site works commenced in November 2011 and commissioning was successfully completed in August 2012 producing 1.3 MW of peak AC power.

B. Key Statistics

Table III presents some key details related to the solar farm construction. The farm comprises of 5,760 poly silicon photovoltaic panels generating 1.32 MW peak (DC). 240 SolarGiant frames on 480 concrete blocks anchor down the solar panels and cyclone proof them. An approximate annual production of 1,880 MWh is generated per annum supplying approximately 4 % of Tongatapu's annual energy demand.

C. Project Challenges

The solar farm was originally expected to be 100 % owned and operated by Meridian Energy for 20 years with a Purchase Power Agreement [12]. Financing structure for the project included a joint venture between NZAID grant of \$NZ 2.5m, Government of Tonga's investment of \$NZ 2m and a 20 year concessional loan of more than \$NZ 2.0m at an interest rate of 2.5 % from the European Investment Bank (EIB) [13]. The project financing structure would result in ownership transfer to TPL after 20 years. Asset life of solar panels have an expected lifetime of 35 years, allowing possible 15 years of production at low cost to TPL [14].

The project had a commercial focus from Meridian Energy with direct benefits to Tonga that aligned with the TERM goals. Benefits to Tonga included;

- a reduction in annual diesel requirements by up to 475,000 litres per annum,
- local employment opportunities and capacity development,
- regional showcase for renewable energy generation [14].

The path to development of the project faced many political, legal and institutional challenges as a joint venture. Originally proposed project structure is presented in Fig. 2 The project financing was restructured with an alliance of four parties as below [12];

- NZAID - provide full project funding on a grant basis
- Meridian Energy - developer, legal owner, operator and maintenance (O&M) for a period of 5 years
- TPL - long term owner and O&M
- Government of Tonga - regulatory support and removal of roadblocks

The restructured project is a sensitive topic in the Tongan energy sector with potential political implications. Although it is difficult to gather data on record for such a politically sensitive topic, it is understood that Meridian Energy had considered exiting it's involvement in the project when it no longer became commercially viable. At the request of the New Zealand government and with full funding support from NZAID, Meridian Energy, a New Zealand state owned enterprise continued its involvement as the developer.

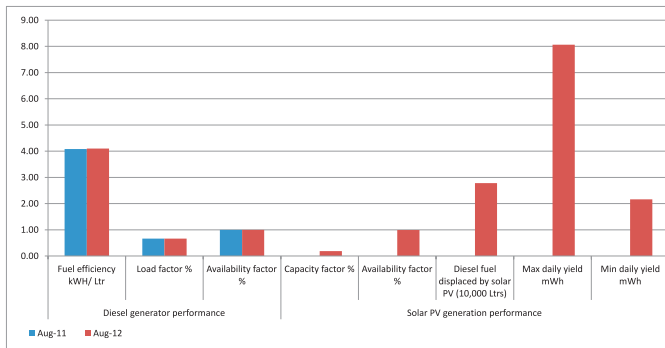


Fig. 4. Generator Performance for August 2011 and 2012

The official project operational handover to TPL was completed in August 2012 and legal ownership transfer is expected in 2017 [10].

D. Results

Fig. 3 and Fig. 4 compares generation, demand and generator performance for the month of August in 2011, and 2012 following the commissioning of the solar farm in July 2012. Diesel generated energy was lowered by 106 MWh in 2013, reducing energy generated by consuming diesel. The total energy demand, peak and minimum loads for the month have nominal changes between the two years. The energy generated by solar was 115 MWh, 3.2% of the total 3596 MWh generated in August 2012. Literature on the integration of renewable energy in a diesel base often suggests that the fuel efficiency of diesel generator is likely to reduce with intermittent renewable systems. In this case, at peak solar generation of 1.3 MW and total generation of 4.7 MW, diesel efficiency is not compromised whatsoever. Even though the intermittent renewable energy penetration is well above the internationally recommend 15% penetration range [15].

Figures 5 to 7 present a typical 24 hour profile of the photovoltaic system's real power generation, a base load supply diesel generator unit's real power supply, and the system frequency. The photovoltaic system generation varies intermittently, based on the sunlight illumination on the photovoltaic modules. The peaks seen in Fig. 5 occurred with the maximum sunlight illumination and the troughs indicate cloudy periods with little sunlight reaching the photovoltaic modules' surface.

The system frequency in Fig. 7 is noted to be within 1.0% with a high value of 50.13 Hz and a low value of 49.87 Hz, showing early warnings towards system instability. Presently, diesel generators provide peak demands in the evenings when there is no sunlight and also provide a buffer for up to 30% intermittent generation by photovoltaic systems. With additional renewable energy mix in the grid, diesel generators are likely to stay in order to supply the peak demand in evenings (when there is no sunlight), and also to provide a buffer during intermittencies associated with renewable energy such as wind and solar. However, existing diesel generators come with limitations and cannot support a 100% of intermittent renewable energy generation mix without the support of

energy storage system such as a large battery bank.

The overall project was implemented with a budget of \$7.9 m for 1.3 MW, totaling a cost of \$6.07 per watt peak.

IV. CASE STUDY 2; TONGAN SCHOOLS GO SOLAR

During June and July 2012, a group of volunteers from New Zealand worked with the Kingdom of Tonga Ministry of Education and Training (MET), Tonga Power Ltd. (TPL) and JH Electrical Contractor and Supplies (JH), to install solar PV power systems of 8 kWp in five Tongan high schools. The installations were a part of the Solar PV and ICT Pilot Programme for Tongan schools initiated by a New Zealand based NGO EcoCARE Pacific Trust (EcoCARE) in partnership with MET [16]. EcoCARE engaged University of Canterbury (UC) staff, student and alumni volunteers for the design, procurement and installation purposes. Engaging volunteers via UC provided capable and interested individuals to partially satisfy their academic, practical and personal interests while carrying out the works required for the project.

The project was initially conceptualised in 2009 by EcoCARE with the intention of installing solar power systems in all Tongan high schools to reduce the burden of electricity related costs in schools and to enable greater use of information and communication technologies (ICTs). The project was funded by the New Zealand Ministry of Foreign Affairs and Trade and financially administrated by Rotary New Zealand World Community Services Ltd. (RNZWCS)

A. Selected School Locations

MET selected recipient schools based on a criteria from EcoCARE to select a diverse a group of schools located in the main island of Tongatapu with existing infrastructure to house PV installations. Concentrating on the comparatively well-resourced island of Tongatapu with easy access to infrastructure during the pilot stage of the project had advantages. Project partners would familiarize themselves with challenges and lessons that could be applied for works in the more remote and challenging islands at a later stage. The geographic locations of the five schools in Tongatapu are shown in Fig. 8.

B. System Design

This "pilot project" was anticipated for future expansion with the possibility of all Tongan high schools receiving solar PV energy systems. Two separate "one size fits all type" systems were designed and implemented in parallel, in order to "test out" a more successful design from the perspective of user friendly maintenance and manufacturer/supplier service support.

System Design A; Suntech PV modules with Power One Aurora inverter

An array of 16 Suntech STP 250 panels were connected in series and terminated to each Maximum Power Point Tracking (MPPT) PV input with a standard test condition (STC) of 491.2 V DC and a short circuit current of 8.63 A. The PV array's electrical parameters were matched as best as possible to the optimum inverter efficiency requirement.

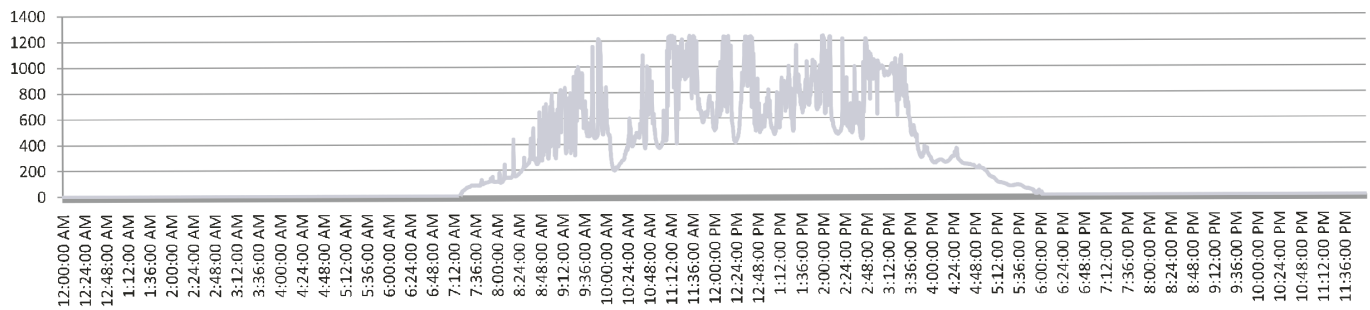


Fig. 5. Twenty Four Hour Solar Generation (Unit G8) kW Profile Measured on 31 August 2012

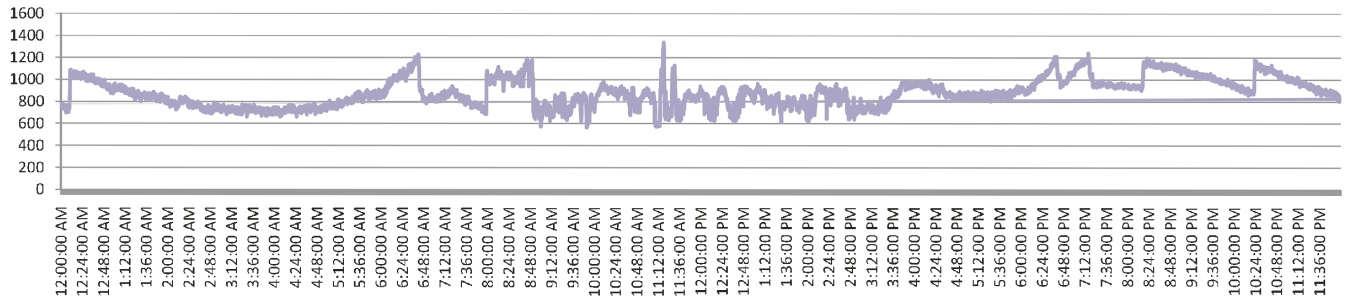


Fig. 6. Twenty Four Hour kW Profile Measured on 31 August 2012 (Diesel Unit G2)

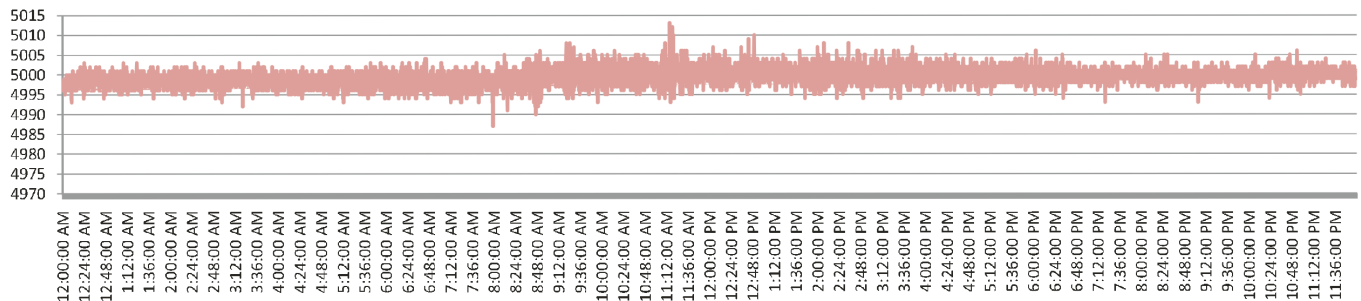


Fig. 7. Twenty Four Electrical Frequency Measured on 31 August 2012 (Diesel Unit G2)

The Aurora inverter is expected to perform at an efficiency of approximately 97.5% and provide a maximum PV power generation of 7.8 kW under the STC. The 3 phase AC output from the Aurora inverter was connected to a 3 phase protection system and terminated to the 3 phase 415 V, AC mains supplied by TPL. The PV array frames were earthed to provide equipotential bonding and terminated to the existing switchboard's earth link in each case. Fig. 9 shows the system schematic for Design A.

System Design B; Suntech PV modules with Enasolar inverter

A PV array of 11 Suntech STP 250 panels were connected in series and terminated to the MPPT input of a single phase 3 kW Enasolar inverter. The array would reach a maximum of 337.7 V with a short circuit current of 8.63 A under the STC. The PV array's electrical parameters were within the inverter's requirement. The Enasolar inverter is expected to perform at

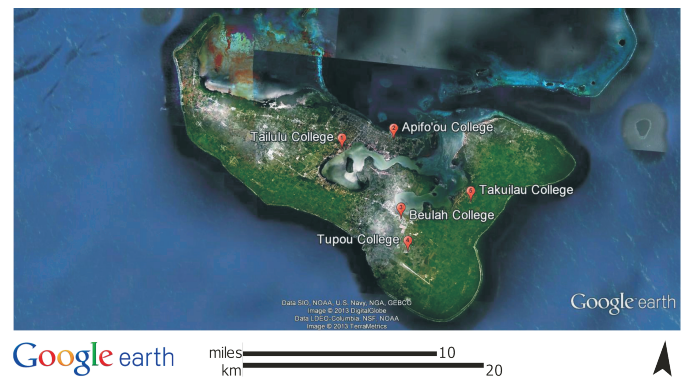


Fig. 8. The island of Tongatapu and location of five PV system installation recipient schools.

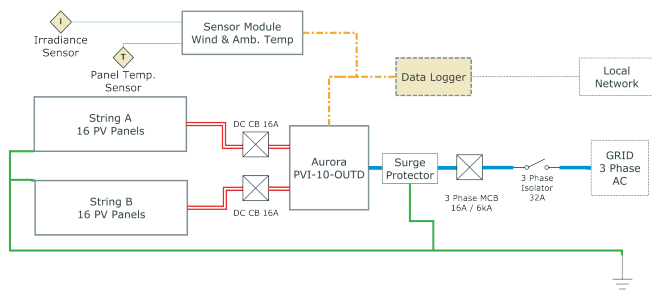


Fig. 9. Design A schematic installed in Takuilau College & Beulah College.

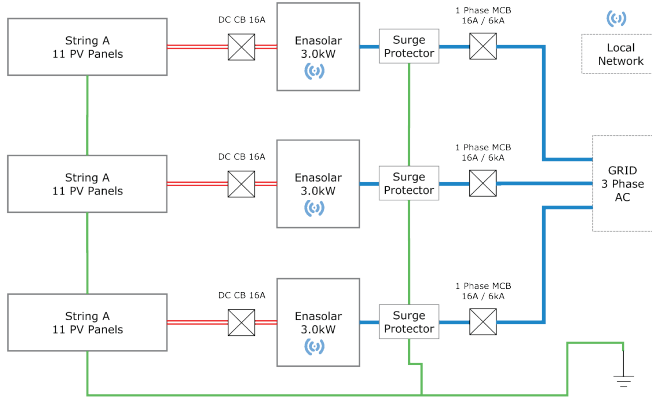


Fig. 10. Design B schematic installed in Tupou College, 'Apifo'ou College & Tailulu College

an efficiency greater than 96.5 % and provide a maximum PV power generation of 2.65 kW under the STC. The single phase AC output from the Enasolar inverter was connected to a single phase protection system and terminated to one of the three phases of the 415 V AC mains supplied by TPL. Two more identical single phase Enasolar systems were terminated to the remaining two phases of the 415 V AC mains, supplying a combined maximum total power of 7.95 kW. All three PV array frames were earthed to provide equipotential bonding and terminated to the existing switchboard's earth link. Tupou College, 'Apifo'ou College and Tailulu College received installations of this system. The Design B schematic is shown in Fig. 10.

C. Metering, Ownership and Tariff Arrangement

Metering

The present metering diagram is shown in Fig. 11. The existing TPL meters in schools (Meter A) measures TPL network export Wh values, the consumption of energy by the school. A new meter (Meter B) measures the TPL network import Wh values, the generation from solar PV system injected into the network. Meters A and B are read on a monthly basis for revenue purposes. Neither of these two meters have smart metering, bidirectional metering or remote data retrieval capabilities.

The EDM MK10A meters (Meter C) were installed as check meters to measure the net flow of power exported to and

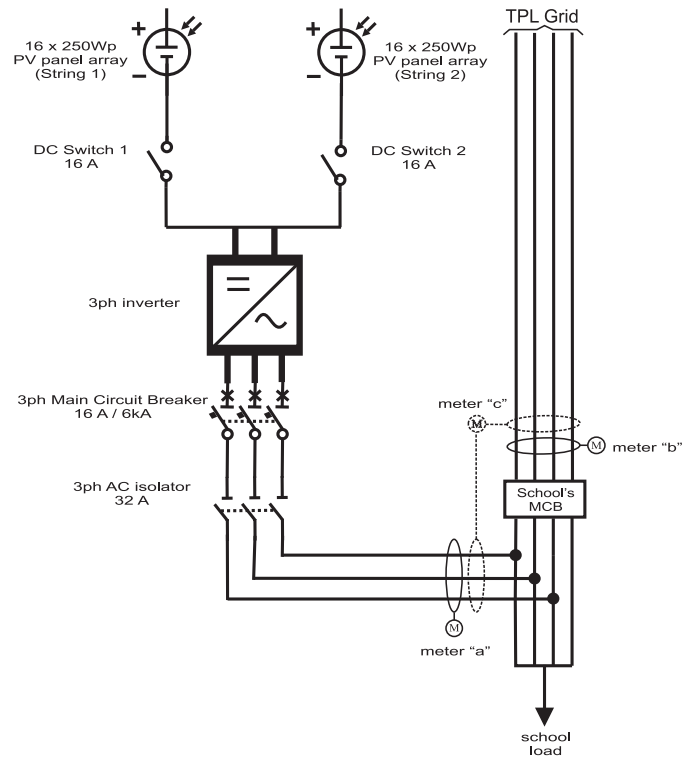


Fig. 11. Design A Schematic and Metering Schematic

imported from the TPL network. The present TPL distributed generation (DG) metering policy was established during the installation of this project and TPL decided to test smart MK10A meters in parallel with TPL familiar meters before using them for trading purposes, a standard industry practice. TPL are presently investigating a greater utilisation of smart meters for the purposes of revenue metering, prepaid crediting and remote data collection for on-going monitoring and billing purposes. MK10A meters are of Class 1 accuracy, capable of measuring bidirectional 3 element 4 quadrant energy values with accuracy better than 1 %. They log salient information such as power quality indicators and events based on configured intervals, and allow remote data retrieval via General Packet Radio Services (GPRS) radio transmission of small packets of data via cellular phone Subscriber Identification Module (SIM) cards.

System Ownership The system ownership was handed over to TPL, at the request of MET and acceptance by TPL due to their existing capacity and technical expertise to own and maintain technical power systems.

Tariff agreement The signed Memorandum of Understanding (MoU) between EcoCARE, MET and TPL included an agreement on the tariff benefits to schools.

- 1) TPL has agreed to pay a daily roof rental fee to each school for housing TPL assets.
- 2) TPL has agreed to pay each school a per unit tariff rate for the generation of electricity.

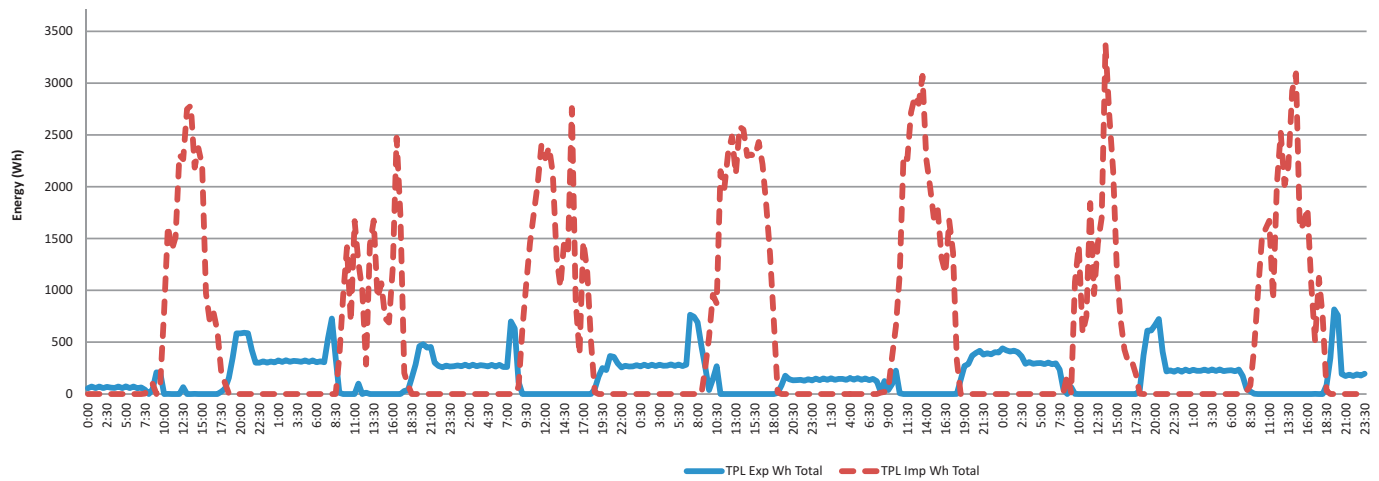


Fig. 12. Takuilau College Half Hourly Real Energy Injection and Consumption, 20 - 26 August 2012

D. Results

The PV installations at all five schools are in operation. Takuilau College was the first of the five schools to be installed and commissioned. Half hourly logs of TPL network energy export to and energy import from Takuilau College over a period of one week during the normal school term are presented in Fig. 12. During the day when the sun is shining, the PV system generates electricity. The difference between this and the school's energy use is imported to the TPL network (red line). During the night there is no PV generation and hence the export from TPL (blue line) is serving the school's night time load, a fridge, freezer, security lighting and internet router.

E. Financials

The cost of the project comes to a total of \$209,430 resulting in a cost of \$5.14 per watt of capacity. A total remaining balance of \$118,900 was in surplus and returned to MFAT by Rotary in April 2013, in completion of the project. The remaining balance was in part, due to successful procurement negotiations and partly due to the reduction of global wholesale cost of PV panels.

V. CONCLUSIONS

There is strong support from international donor partners for the Kingdom of Tonga's goal of realizing their goal of achieving 50% electricity through renewable generation. Political issues, lack of a strong implementation or business plan and the lack of inclusion of in country technical experts are seen to be some of the key reasons behind the delay in TERM progress.

Case study one, Tongas first solar farm was commissioned in August 2012 and was well within the eighteen month TERM plan to execute phase 0 /1 projects. Early results show a reduction in the sales of diesel fuelled electricity and a reduction in diesel generation for the month of August by 106 MWh, helped by the solar production of 115 MWh.

Case study two, donor supported distributed systems such as the schools' 8 kWp solar installations have proven to add economic value to schools while exporting surplus energy into the grid, in support of the national plan.

However, TERM's objective to, "reduce Tonga's vulnerability to oil price shocks and to achieve an increase in quality access to modern energy services in an environmentally sustainable manner" will take some time to be realised. Renewable energy generation by MWh was only 3.2% for the month of August in 2012, far from the originally intended target of 50%.

VI. ACKNOWLEDGEMENT

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